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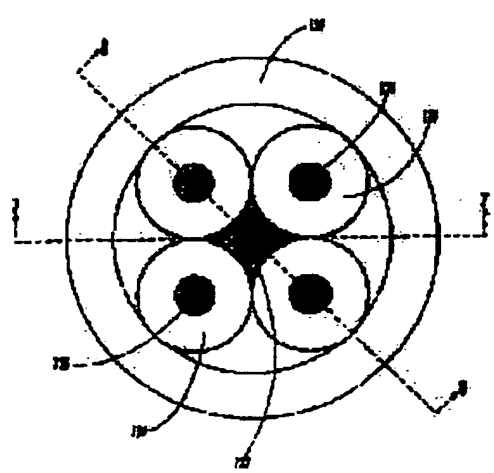
(54) SURFACE-EMITTING LASER AND MANUFACTURE THEREOF

(57)Abstract:
PROBLEM TO BE SOLVED: To provide a compact VCSEL structure, usable for defining lasing openings of a laser structure in which the definition of its oxidized regions and control are done superiorly.
SOLUTION: Using cavities 126 disposed on a specified pattern in a laser structure, oxidized regions 124 are formed. Lasing openings 122 are non-oxidized regions surrounded by these regions 124 with centers at the cavities. During oxidation processing, an Al-rich AlGaAs layer embedded in a semiconductor structure is oxidized, until the oxidized regions 124 between the two adjacent cavities 126 overlapping radially outwards from these cavities.



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CLAIMS

[Claim(s)]
[Claim 1] Are the surface luminescence laser which has a luminescence front face, and said laser contains a substrate. The first reflector to which one of said semi-conductor layers was located in inside at said one barrier layer side including the barrier layer which has an active region including two or more semi-conductor layers formed on said substrate, A part of light energy is made to penetrate through at least one of said reflectors including the second reflector located in the opposite hand of said barrier layer. One of said semi-conductor layers is a current control layer, and two or more cavities prolonged in said current control layer are included. It has the aperture which controls the current which passes along said barrier layer in said current control layer. Said aperture field is demarcated by the conductive field in said current control layer surrounded by the non-conductive field in said current control layer. Each of said non-conductive field is surface luminescence laser with which one cavity is surrounded and these electrodes make bias of said active region possible at the both sides of said laser including the first and the second electrode, respectively.
[Claim 2] Surface luminescence laser according to claim 1 said whose current control layer is an oxidizing zone, said whose conductive field is the part into which said oxidizing zone has not oxidized and said whose non-conductive field is the part into which said oxidizing zone oxidized.
[Claim 3] Are the manufacture approach of surface luminescence laser of having a luminescence front face, and the step which forms a substrate is included. One of said semi-conductor layers contains a barrier layer including the step which forms two or more semi-conductor layers on said substrate. Other one layer of said semi-conductor layer is arranged at a boundary pattern including a current control layer. The step which forms two or more cavities prolonged into said current control layer from said luminescence front face is included. The field of said surrounding current control layer of said cavity is oxidized including the step which exposes the part of said current control layer to an oxidization environment through said cavity. Extend said field, bring a mutual field close, and the step which forms a central non-conductive field among these fields is included. And the manufacture approach of the surface luminescence laser which makes bias of said active region possible with these electrodes including the step which forms the first and the second electrode in the both sides of said laser equipment, respectively.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention] Generally this invention relates to semiconductor laser. A compact and the vertical mold cavity surface luminescence laser demarcated good can be dramatically formed more in a detail by this invention.
[0002]
[Description of the Prior Art] Solid-state semiconductor laser is important equipment in the application of photoelectron communication system, a high speed printing system, etc. Although, as for current, the generality activity of the edge luminescence (edge emitting) laser is carried out in these applications, the interest about vertical mold cavity surface luminescence laser (vertical cavity surface emitting laser, "VCSEL") has increased in recent years. The reason by which the interest increased in VCSEL is that it is difficult for edge luminescence laser to converge the beam discharged since beam spread was large. Furthermore, edge luminescence laser cannot be tested until the cleavage of the wafer is carried out to separate equipment (the edge forms the mirror facet of each equipment). On the other hand, not only the beam of VCSEL has small beam spread, but VCSEL emits light in a vertical light on the surface of a wafer. Furthermore, a design top mirror unifies at VCSEL, it is incorporated, and manufacture of the test of a wafer and-dimensional [1], or a two-dimensional laser array is attained by these mirrors.
[0003] The known technique of manufacturing VCSEL is based on a side-face oxidation process, and is illustrated by drawing 1 and drawing 2 . By this approach, the laser structure containing two or more layers is formed on a substrate 10. These layers contain a barrier layer 12 and the AlGaAs layer 14 with a high aluminum content. The AlGaAs layer 14 is arranged on the barrier layer of laser structure, or at either the bottom. Next, this layer structure is masked, it is etched selectively, and the mesa structure 22 (it illustrates to drawing 2) is formed. As a result of etching, the AlGaAs layer 14 with the high aluminum content which adjoins a barrier layer 12 is exposed to the edge of the mesa structure 22. In order to form a raising radiation zone, i.e., "aperture", this AlGaAs layer oxidizes in a longitudinal direction from an edge toward the core of mesa structure, as expressed with the arrow head A. Since the aluminum content is lower than an AlGaAs layer, other layers in this structure remain not oxidized intrinsically. Therefore, these oxidation quotients are also substantially low. Therefore, only an AlGaAs layer with a high aluminum content oxidizes. The part into which the high aluminum content layer oxidized serves as non-conductive electrically as a result of oxidation treatment. The field (conductivity) where it remained in the AlGaAs layer and which has not oxidized forms the so-called "the aperture (opening)", this aperture is a field which defines the current pass in laser structure, and, thereby, a laser luminescence field is decided. VCSEL formed by such technique is indicated by "the vertical mold cavity surface luminescence laser Electronics Letters whose power efficiency is 50% and which oxidized selectively (Selectively Oxidized Vertical Cavity Surface Emitting Lasers With 50% Power Conversion Efficiency)", Vol.31, and pp.208-209 (1995).
[0004] The current side-face oxidization approach has some faults, such as large [an oxidization field] and deficient [large / mesa structure / and] in control of aperture size. The main faults of this approach

are that control of the amount of oxidation is difficult. Generally, desirable equipment aperture is 1-10 microns (micrometer) order, and this means that dozens of microns (it must generally be the magnitude of 50-100 microns) side-face oxidation is generally required, in order to oxidize from the side face of a bigger mesa and to manufacture equipment. Consequently, since the size of aperture becomes small compared with the range of a side-face oxidation field, it reaches with a wafer and, generally, as for the formed equipment, has big dispersion in aperture size the result which is not fixed of the one specific wafer. It depends for the oxidation quotient of AlGaAs on the aluminum component greatly. The non-homogeneity of all components is reflected by change of an oxidation quotient, and, thereby, a uncertainty produces it in the amount of oxidation. This process is also comparatively sensitive to temperature again. Since the oxidation quotient is various, it is difficult to ensure extent which oxidizes the laser structure, and, thereby, the repeatability of the performance of equipment decreases. That is, such a process produces various manufacture problems and a production problem.

[0005] Other faults of VCSEL formed by the traditional side-face oxidation approach are problems produced in case a high density laser array is formed. In order to oxidize a buried layer with a high aluminum content, it leaves a mesa and an etching process is performed. The laser aperture of specific size is demarcated after etching of this mesa by the field which performed side-face oxidization and oxidized. The minimum tooth space between two laser in one array is selectively restricted using mesa structure. Since it is necessary to etch the height of the step of this mesa through a thick up DBR mirror, generally it is several microns. Furthermore, it is necessary to also enlarge the top face of a mesa comparatively so that a metal joint can be formed on this mesa, without closing raising aperture. typical -- the minimum size of electric contact -- about 50 -- x50micrometer2 it is . Therefore, it is difficult by arrangement of the height of the step of a mesa, and electric contact to the front-face top to form the laser array of the **** high density which is very a compact.

[0006] The solution over some of problems about typical mesa structure is using a shallow mesa. In order to use a shallow mesa, an up mirror is not formed of epitaxial processing. Instead, an up mirror is formed with the dielectric matter of two or more layers to which it adhered, and, thereby, reflects light. Electric contact is directly created on the upper part of an active region. The equipment formed by this approach was manufactured on the mesa which has width of face of about 12 microns. However, the dielectric matter is made to adhere and it is difficult to optimize the low threshold current and the high efficiency of equipment by the further complexity of demarcating a contact using a lift-off (liftoff) process.

[0007] VCSEL formed by the traditional side-face oxidation approach at the end has that mechanical integrity or structural integrity is often scarce. Since adhesion of the oxidizing zone to GaAs or AlGaAs which has not oxidized is generally weak, the laminating of the whole mesa may be broken down with the above pressure added into the packing (mounting) process.

[0008]

[Problem(s) to be Solved by the Invention] This invention offers the very compact VCSEL structure which can be used in order to demarcate the raising aperture of laser structure and by which the oxidation field was demarcated and controlled appropriately. These oxidization fields are formed into laser structure using two or more cavities arranged at the predetermined pattern. Raising aperture is a field which was surrounded by these oxidation fields centering on these cavities and which has not oxidized. Between oxidation processes, it oxidizes until the oxidation field between two adjoining cavities overlaps the AlGaAs layer with the high aluminum content embedded into semi-conductor structure in the radiation direction towards an outside from each of these cavities. The AlGaAs layer with the high aluminum content for forming an oxidization field and the aperture section is often called a "oxidizing zone."

[0009] The oxidization area size to which the advantage of this invention demarcates raising aperture is the about the same as the magnitude of the raising aperture itself. Generally, the oxidation quotient of these of AlGaAs is dramatically uneven depending on a matter component and a processing parameter. As for such heterogeneity, impact becomes small as the ratio of : (size of an oxidization field) (size of the last laser aperture) becomes small. When the amount of oxidization required to form raising aperture

when it puts in another way is reduced substantially, aperture size stops receiving effect in change of the matter and a process not much. This becomes suitable demarcation of aperture, and controllable.
[0010]
[Means for Solving the Problem] The first mode of this invention is surface luminescence laser which has a luminescence front face. The first reflector to which one of said semi-conductor layers was located in inside at said one barrier layer side including the barrier layer which has an active region including two or more semi-conductor layers by which said laser was formed on said substrate including the substrate, A part of light energy is made to penetrate through at least one of said reflectors including the second reflector located in the opposite hand of said barrier layer. One of said semi-conductor layers is a current control layer, and two or more cavities prolonged in said current control layer are included. It has the aperture which controls the current which passes along said barrier layer in said current control layer. Said aperture field is demarcated by the conductive field in said current control layer surrounded by the non-conductive field in said current control layer. Each of said non-conductive field surrounds one cavity, and these electrodes make bias of said active region possible at the both sides of said laser including the first and the second electrode, respectively.
[0011] The second mode of this invention is surface luminescence laser [which was indicated in the first mode] said whose current control layer is an oxidizing zone, said whose conductive field is the part into which said oxidizing zone has not oxidized, said whose non-conductive field is the part into which said oxidizing zone oxidized.
[0012] The third mode of this invention is the manufacture approach of surface luminescence laser of having a luminescence front face. The step which forms two or more semi-conductor layers on said substrate is included including the step which forms a substrate. In one of said semi-conductor layers, other one layer of said semi-conductor layer contains a current control layer including a barrier layer. It is arranged at a boundary pattern and the step which forms two or more cavities prolonged into said current control layer from said luminescence front face is included. The field of said surrounding current control layer of said cavity is oxidized including the step which exposes the part of said current control layer to an oxidization environment through said cavity. Said field is extended, a mutual field is brought close, and bias of said active region is made possible with these electrodes including the step which forms the first and the second electrode in the both sides of said laser equipment, respectively, including the step which forms a central non-conductive field among these fields.
[0013]
[Embodiment of the Invention] Drawing 3 expresses the semi-conductor structure used for forming the gestalt of suitable operation of this invention. These are used in order that the illustrated structure may form vertical mold cavity surface luminescence laser including many semi-conductor layers. It sees, and these layers are only expressed as schematic drawing, and each relative thickness is not related at all as it understands. As expressed to drawing 3 R> 3, about 200nm n mold-GaAs buffer layer 102 is grown up on the n mold-GaAs substrate 100 using the epitaxial vacuum evaporationo processing known as organic metal chemical vacuum deposition ("MOCVD"). Generally it is at least 3x1018cm-3-7x1018cm-3 so that resistance [in / in the doping level of an n mold-GaAs substrate and a GaAs buffer / these layers] may become low moderately. It can also adhere to these semi-conductor layers on a substrate again according to liquid phase epitaxial growth ("LPE"), molecular-beam crystal growth ("MBE"), or other known crystal growth processes.
[0014] There is a superstructure which forms the lower distribution Bragg reflector (DBR and Distributed Bragg reflector) 104 on the GaAs buffer layer 102, and required internal reflection is offered in VCSEL structure. The lower part DBR104 is formed of two or more pairs which consist of an AlGaAs layer with the typically high content of aluminum, and other AlGaAs layers with the low content of aluminum. The increase of the number of the pairs of a layer, and after carrying out, it adheres to a last AlGaAs layer with a high aluminum content, and the first ************** layer 106 of an optical cavity is grown up after that. The thickness with the pair of each class typical for 820nm laser luminescence is about 120 nanometers. A pair of overall thickness of each class is designed so that it may become equal to the one half of light wave length in the wavelength on which laser actuation was

meant. The thickness of the last high aluminum content layer is designed so that it may become equal to the quarter of light wave length in the wavelength on which laser actuation was meant. This AlGaAs layer with a high aluminum content contains aluminum about 86%. The aluminum content of an AlGaAs layer with a high aluminum content is not so high as it oxidizes simply, although it is high enough for offering a low refractive index. The AlGaAs layer with a low aluminum content has about 16% of aluminum content. Generally the component of an AlGaAs layer with a low aluminum content contains the aluminum of as sufficient amount as it is unabsorbent on the raising wavelength.
[0015] With the gestalt of this operation, since light carries out an outer join through the top face of a semi-conductor sample, in order to make internal reflection high, near of the reflection factor of the lower part DBR104 should be made 100% as much as possible. If the rate of internal reflection is generally high, the threshold current of laser will decrease. It is known well that the reflection factor of the lower part DBR104 is generally the function of the difference of the refractive index of two AlGaAs layers of superlattice and a pair of number of the layers in the structure. If the difference of this refractive index is large, there will be few a pair of numbers required to obtain a given reflection factor, and they will end. Generally 30-40 pairs of AlGaAs layers are used to form the lower DBR structure 104.
[0016] After adhering the lower DBR structure 104 by epitaxial processing, the AlGaAs ************** layer 106 is adhered. The aluminum content of this lower AlGaAs ************** layer 106 is about 58%, and is n mold of doping level 1 x1018cm-3-5x1018cm-3. The thickness of this layer is about 100nm. On this AlGaAs ************** layer 106, there is a barrier layer 108 of laser structure and these quantum wells are divided by three barrier which has the thickness of 2-8nm including four quantum wells which have the thickness which is 5-10nm. Therefore, quantum well structure is formed in the output wavelength of a request of laser structure using pure GaAs or AlGaAs with a low aluminum content. With the gestalt of this operation, these quantum wells are typically formed of AlGaAs which has about 7% of aluminum content and which is not doped. In this invention, although a barrier layer 108 is formed, the activity of a single quantum well or other two or more quantum well ("MQW") structures is not barred.
[0017] A barrier layer 108 top is the up AlGaAs ************** layer 110, and this ************** layer 110 resembles the lower AlGaAs ************** layer 106 structurally, if the polarity of that dopant is removed. Besides, although the section ************** layer 110 has about 58% of aluminum content, it is p mold which has the doping level of 1x1018cm-3-4x1018cm-3. The thickness of the top ************** layer 110 as well as the lower AlGaAs ************** layer 106 is about 100nm. These two AlGaAs ************** layers 106 and 110 form an optical cavity in general with a barrier layer 108, and desired optical gain is acquired in this cavity. The total thickness of layers 106, 108, and 110 is adjusted equally to the integral multiple of the wavelength which laser actuation means.
[0018] The up AlGaAs ************** layer 110 top is an oxidizing zone 112, and it is used for forming laser aperture. This laser aperture controls the flow of a current and, thereby, controls the raising location in a barrier layer 108. With the gestalt of this operation, this oxidizing zone 112 exists on the up AlGaAs ************** layer 110. In this invention, it does not bar transposing this oxidizing zone 112 to other locations (or on [Barrier layer 108 / More] or under). Typically, this oxidizing zone 112 has about 95% of aluminum content, and the thickness of about 70nm. Typically, this oxidizing zone 112 constitutes the first pass of an up DBR mirror, and contains p mold-dopant.
[0019] After an oxidizing zone 112 is formed, the remaining up DBR mirror 114 containing p mold-dopant is adhered. The up DBR mirror 115 resembles the lower DBR mirror 104 structurally, if the polarity of the dopant is removed. Furthermore, generally the mirror layer nearest to each ** of an active region has a high aluminum content. In the gestalt of this operation, this high aluminum content layer is also an oxidizing zone 112. With the gestalt of this operation, since light carries out the outer join of the reflection factor of the upper part DBR114 through the front face of a semi-conductor sample, it is 98% - 99% typically. Generally for besides forming the section DBR mirror 114, 20-25 pairs of mutual AlGaAs layers are used.
[0020] Drawing 4 is some top views of the mask which may be applied to the semi-conductor structure

expressed under this invention to drawing 3 . First, the homogeneity layer of silicon nitride is made to adhere to the whole semi-conductor sample as usual. Next, a photoresist layer 118 is made to adhere on this silicon nitride layer, a photoresist ingredient is removed from four round fields 120, and a mask like drawing 4 is made to form with photolithography. These round fields 120 form the boundary pattern decided beforehand, and it is used for this demarcating the final aperture of laser structure behind.
[0021] As expressed to drawing 5 , etching processing is performed to this sample and the cylindrical shape cavity 126 is formed into semi-conductor structure through four exposed round fields 120 which was exposed to etching processing in the meantime. Etching is performed by processing of reactive ion etching etc. and the deep hollow which has a vertical mold side attachment wall is formed. The depth of each cylindrical shape cavity reaches even an oxidizing zone 112 at least (it illustrates to drawing 5). After a cylindrical shape cavity is formed and all the photoresists on a front face are removed, oxidation treatment is performed to this semi-conductor sample. This sample oxidizes in a nitrogen environment using a steam at the elevated temperature exceeding 350-degreeC typically. An oxidizing zone 112 is exposed to a perimeter through each cylindrical shape cavity during this oxidation treatment (an arrow head B illustrates). In this way, generally, the oxidizing zone 112 which consists of AlGaAs with a high aluminum content oxidizes in the radiation direction toward an outside from each cavity 126 until the oxidization field 124 which surround each cavity approaches mutually and overlaps it (it illustrates to drawing 6). However, as long as electric field and the optical field (optical field) are the range restricted moderately, the non-oxidizing gap between oxidation fields may be small. Although the cross section of each cavity has been indicated as what is a cylindrical shape, what kind of suitable cross section may be used.
[0022] Since other layers between oxidation processes and in structure have the low aluminum content, they remain hardly oxidized. In constant temperature, it becomes high in general exponentially while the aluminum content of the oxidation quotient of AlGaAs increases. The time amount of oxidation treatment is decided by the aluminum content and oxidation temperature of an oxidizing zone 112. Desirable controllable oxidation time amount is dozens of minutes. Therefore, the layer which has oxidized is AlGaAs which has an aluminum content near 95%. The part which remains with an AlGaAs layer not oxidized controls the current pass which passes along a barrier layer 108.
[0023] Drawing 6 is the amplification schematic plan view of the oxidizing zone 112 expressed to drawing 3 , and assumes the place which removed all the layers on this layer. The shadowed part 122 expresses the laser aperture in an oxidizing zone 112, and this aperture appoints the field of laser luminescence by the barrier layer 108. This aperture is formed of the oxidation process of this invention. Between oxidization processes, an oxidization front (oxidation front) progresses through an oxidizing zone from the pattern which consists of four cavities 126, and the shadowed part 122 is formed of the intersection of the borderline of the oxidization field 124. It becomes the oxidization field 124 which the oxidization front emitted from the cylindrical shape cavity 126 is also a cylindrical shape mostly, and overlapped it. The center of the overlap field 124 remains not oxidized. This field that does not oxidize forms the shadowed field 122, and this is the aperture of laser structure. An insulating region 130 is formed after an oxidation process using an ion-implantation process (it indicates below), and laser structure is isolated from the thing around it.
[0024] After an oxidation process, a field 124 oxidizes and the part 122 which does not oxidize forms the aperture which controls the current pass which passes along a barrier layer 108. The flow of the current which passes along the part concerned of the barrier layer 108 under aperture 122 becomes p mold and n mold carrier injection concentration (injected density), and light is amplified. When the flow of a current is high enough, laser oscillation and luminescence produce magnification of this light from a barrier layer in the field demarcated by the aperture 122 in an oxidizing zone 112 conjointly with the feedback from the DBR mirrors 104 and 114.
[0025] The insulating region 130 (it illustrates to drawing 6 , drawing 7 , and drawing 8) formed using an ion-implantation insulation (isolation) process has high resistance. The typical impregnation energy used for such a process is 50KeV(s), 100KeV, and 200KeV(s). Generally dosage is 3x1015cm-2 in each energy level. The ion used for forming an insulating region 402 is hydrogen.

[0026] The metal contacts 132 and 144 for carrying out bias of the laser, respectively are formed in the top face and base of semi-conductor structure after an insulating process (it illustrates to drawing 7 , drawing 8 , and drawing 9). The typical metal used for forming these contacts is the two-layer film of titanium/gold.
[0027] Drawing 9 expresses the top view of the VCSEL structure formed according to this invention, after forming the top-face contact 132 according to a general metallization process. The sectional view cut off by the line 7-7 of this drawing and 8-8 is expressed to drawing 7 and drawing 8 . The top contact 132 is a keyhole mold mostly, and contains the annular part 134 and an extension 136. There is an annular part inside a cavity 126 (inboard), and it has hung on the laser aperture 122. Since this is not transparent, this is annularly made so that the light from laser may be combined through central aperture (since it is nontransparent nature). Width-of-face"W" of the annular part 134 is restricted by the minimum line width of face which can usually be attained under the processing technique used, and, thereby, sets up the minimum of the pitch between adjoining VCSEL structures. Therefore, the typical pitch between the cores of two adjoining VCSEL aperture 122 is "4W." However, since a top-face contact may hang on the laser aperture 122 when using a transparent conductor, the pitch between the adjoining VCSEL structures is further reducible. Therefore, this pitch may be reduced to the order of "2W", as expressed to drawing 10 . A typical conductor is indium oxide tin and this may be made to adhere according to a sputtering process. The gestalt of other operations of a top-face contact is expressed to drawing 10 , and is expressed with the number 138. The contact finger 140 has hung on the laser aperture 122 including the conductive contact finger 140 where this is transparent, and the contact pad 142. After forming electric contact on a top face, a metal is made to adhere to the base of a substrate 100, and the bottom product electrode 144 is formed.
[0028] Drawing 16 , drawing 17 , and drawing 18 express other pack (mounting) arrays for forming the laser array formed by the approach of this invention to drawing 11 , drawing 12 and drawing 13 , drawing 14 and drawing 1515 , and a list. In the array of such equipment expressed to the laser equipment and drawing 12 R> 2 of drawing 11 , these oxidization fields 224 have surrounded the boundary pattern of three cylindrical shape cavities 226 located at the top-most vertices of an equilateral triangle including the aperture 222 by which each laser structure was demarcated by the oxidization field 224. All the tooth spaces between the cores of two cavities are "S." As stated previously, the embedded AlGaAs layer with a high aluminum content oxidizes in the radiation direction toward an outside between oxidation processes from the cylindrical shape cavity 226 until the laser aperture 222 to which the oxidation field 224 overlaps and has not oxidized is formed. The pack array expressed to drawing 11 can be repeated, and a laser array which was expressed to drawing 12 can be formed. When spacing between the cores of two cylindrical shape cavities is set to "S", typical straight-line spacing between two laser aperture (linear spacing, component distance of the direction where the array of drawing 12 extends) is abbreviation "S/2."
[0029] In the array of the laser equipment of drawing 13 , drawing 14 , and drawing 15 , the square boundary pattern which consists of a cylindrical shape cavity 126 is expressed. The oxidization field 124 is overlapped and forms the laser aperture 122 which has not oxidized. A laser array which repeated the pack array expressed to drawing 13 , and was expressed to drawing 14 and drawing 15 can be formed. When using a pack array like drawing 14 and spacing between the cores of two adjoining cylindrical shape cavities is set to "S", typical straight-line spacing"L" between two laser aperture is "S" mostly. When using an array like drawing 15 and spacing between the cores of two adjoining cylindrical shape hollows is set to "S", typical straight-line spacing"L" between two laser aperture is [Equation 1] generally.

"$\sqrt{2} \times S$."

It comes out.
[0030] The boundary pattern of the hexagon which consists of a cylindrical shape cavity is expressed with the array of the laser equipment of drawing 16 , drawing 17 , and drawing 18 . The cavity 326 of arrange [you / at the top-most vertices of other polygons] is clear. As stated even in the place of the

gestalt of operation of point **, laser aperture is formed of the field 322 which was demarcated by the field 324 which oxidized and which has not oxidized. A laser array which repeated the pack array expressed to drawing 16 , and was expressed to drawing 17 and drawing 18 may be formed. When using an array like drawing 17 and spacing between the cores of two adjoining cylindrical shape cavities is set to "S", typical straight-line spacing"L" between two laser aperture is "1.5S" mostly. When using an array like drawing 18 , typical straight-line spacing"L" between two laser aperture is [Equation 2] generally.

"$\sqrt{3} \times 0.5S$."

It comes out.

[0031] And they may change various these parameters. [the constituent mentioned previously, dopant, doping level, and a dimension] [instantiation] Furthermore, other layers may be added to the layer with which it expressed to drawing. Experiment conditions, such as temperature and time amount, may be changed. the last -- instead of [of GaAs and GaAlAs] -- the [GaAlSb, InAlGaP, or / other] -- III-V Other semiconductor materials, such as a group alloy, may be used.

[Translation done.]